

## FOLDING, ARTICULATED, SQUARE TRUSS

Robert M. Warden\*

## ABSTRACT

A larger, stronger deployable boom has been developed to handle the requirements of larger, heavier payloads in space. The main components of the boom and its deployer are described and their functions explained. Desirable features of the boom are identified and physical properties are reported.

## INTRODUCTION

The new generation of experimental payload is larger and more complex than ever before and requires larger and stronger support structures. For example, the Tethered Satellite Experiment is a 590 kg (1300 pound) sphere designed to be deployed 100 km (62 miles) out of the Shuttle, much like trolling with a very large fishing pole (Figure 1). The deployable boom which is the subject of this paper is the "fishing pole". The boom is contained in a canister which is 76 cm (30 inches) in diameter by 152 cm (60 inches) tall (Figure 2). When power is applied to the system, the boom gently pushes the satellite away from the shuttle. When fully deployed, the boom is approximately 12 m (40 feet) long. The boom is unique not only in that it is the largest and strongest of its kind but also the design has many features with other potential applications.

Requirements

The basic requirement was for a compact structure which would deploy the payload away from the shuttle, support the tether during the experiment, and retract the payload when the experiment is finished. A total of 70 electrical conductors must run the full length of the structure while maintaining electrical continuity at all times. The system must retain near full strength and stiffness during deployment and retraction and be able to stop and reverse at any time.

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\* AEC-Able Engineering Co., Goleta, California

Additional requirements are as follows:

Table I: Requirements

Diameter	1.00 M	(39.0 in) max
Retracted Length	1.52 M	(60.0 in) max
Deployed Length	12.0 M	(480 in) min
Deployed Strength	6779 N-m	(6.0 x 10 <sup>4</sup> in-lb) ult
Deployed Stiffness	4.45 x 10 <sup>5</sup> N-m <sup>2</sup>	(1.55 x 10 <sup>8</sup> lb-in. <sup>2</sup> )
Operating Temp	-75 °C +65 °C	(-103 °F) (+149 °F)
Survival Temp	-150 °C +120 °C	(-238 °F) (248 °F)
Life Cycles	160 min	

Existing designs were found to be inadequate for this application. Coilable fiberglass booms stowable in the allowable envelope could not be made with enough stiffness or strength. They were also limited in the number of electrical wires they could support and their rotating base required some sort of derotator or slip-ring assembly. Most such folding structures rely on numerous latches and often have a large "dead band" or free play due to the hinge pins.

The new design incorporates pretensioned joints to eliminate dead band and no latches are used at all. Electrical cables are stored flat and are not subject to any twisting or sharp bends during operation. No slip rings are needed as the mast does not rotate to allow the mechanism to function.

## SYSTEM DESCRIPTION

### Boom

The boom is a four-sided structure which is designed to fold into a flat package for storage (Figure 3). The structure has an excellent compaction ratio of 7.2% which means that a 40-foot-long mast will retract to a length of less than 35 inches.

The geometry of the boom is based on cubical units called "bays". Each bay is designed to fold independently of the others but all of the bays are connected together to form a continuous structure from top to bottom. The individual bays open or close sequentially to deploy or retract the boom. The deployment mechanism will be described after the mast.

An important feature of the mast is that only one bay is in transition at a time. This provides a very stable system in that the mast develops full strength and stiffness even when only partially deployed. Another important feature is that the mast stacks flat without rotating. This makes it easier to handle electrical cables and simplifies alignment.

At each end of a bay is a rigid, "square frame" which controls the square shape of the mast (Figure 4). In the retracted position, the square frames are stacked flat, separated by stacking buttons to provide a load path during launch.

The vertical (or longitudinal) members are called "longerons" and are hinged at mid-bay to allow the square frames to stack when the mast is retracted. The mid-bay elbow joint of the longeron is held straight when deployed by a flexible fiberglass "bow" (which acts as a compression spring) pushing on the joint and "diagonal cables" pulling on the joint. The fiberglass bow also helps deploy the mast in other applications which will be discussed later.

The diagonal cables are tensioned between the square frames and the mid-bay elbow joints across the four faces of the boom. This has the desirable effect of pretensioning all of the joints in the mast and eliminating any dead band.

The key to deploying or retracting the boom (or specifically, each bay) is the mid-bay elbow joint. Controlling this joint causes the bay to open or close. The longerons must fold to allow the square frames to stack flat. To do this, a force is applied at the joint which is opposite to, and greater than, the compressive load of the fiberglass bow. When this force is simultaneously applied to all four joints in a bay, the longerons fold as the bows are compressed. Half of the diagonal cables remain taut to control the folding longeron geometry while the other half become slack and simply fold out of the way.

When closed, a bay is, in effect, slightly spring-loaded to deploy by the force in the fiberglass bow. This force increases rapidly as the bay opens so deploying the bay mainly involves easing the mid-bay elbow joint into place. This process is discussed later in the transition section. Note that no latches are necessary in the deployment or retraction of the boom.

### Electrical Cables

Since this boom is used to push an experiment away from the Shuttle, electrical cables must be provided to connect the experiment to the Shuttle.

Seventy conductors grouped into twisted, shielded pairs and twisted, shielded triplets were needed to run the full length of the boom to the experiment. To make a thinner package, a ribbon cable configuration was used instead of a round bundle. The ribbon cables were prefolded over a relatively small radius and then clamped to the boom (Figure 5). By offsetting the cable attachment point from the hinge line, the cable lays flat when retracted but becomes effectively "too long" for the bay when deployed so that it bends over a large radius which increases the life of the wires. Four different ribbon cable assemblies can be handled this way (one on each face of the boom) and power leads can thus be separated from signal wires.

The cables are folded with the longerons and stored flat between the retracted bays. There is no increase in the height or diameter of the retracted boom because of the addition of the cables.

### Canister

The canister is divided into three main sections: the storage shell, the elevating mechanism, and the transition section (Figure 6). Guide rails run the entire length of the canister to prevent the boom from rotating.

The storage shell contains and supports the retracted boom during handling and launch. It is made of thin aluminum sheet, rolled and welded into a cylinder and supported at each end by machined aluminum rings. The structural interface to the Shuttle support structure is a large mounting ring located near the top of the storage shell. The electrical connector brackets for the electrical leads that run up the boom and for the canister harness are mounted to the lower ring.

The elevating mechanism is a large nut with four helical threads machined on the inside. At the corner of each square frame of the boom is a small roller which can engage in the thread of the nut. The nut is driven by a spur gear on its lower end that also acts as the mechanical support to the rest of the canister. The nut is rotated causing the boom to deploy or retract depending on the direction of rotation.

On other mechanisms using the same deployment principle, large-diameter bearings are used on the top and bottom of the nut for support (Figure 7). Because the bearings are made of steel and the nut is made of aluminum, thermal interference problems occur at high or low temperatures due to different coefficients of thermal expansion. These problems increase with the diameter to such an extent that the free play required to accommodate a large bearing results in excessive dead band.

To solve this problem, a new approach has been taken. A combination gear and bearing race of hard-anodized aluminum is attached to the nut. In place of a continuous bearing, localized bearing support blocks are used. Because all of the large-sized parts are made of aluminum (including the boom), the problem of differential thermal expansion is minimized and clearances can be made much closer. The localized bearings are made of steel but are now of such a small size as to be less affected by thermal extremes. The wedge shape of the ring gear allows the bearings to take axial as well as radial loads. The bearing blocks are mounted to the top of the storage shell and are braced to the main mounting ring. In this way, most of the load from the boom is transferred directly from the nut to the mounting ring.

### Transition Section

The transition section is an area which overlaps the elevating mechanism and the storage shell and contains the device that changes the boom between fully deployed and fully retracted.

By incorporating a special guide, the action of deploying and retracting the boom by the elevating nut is also used to open and close the bays as they pass through the transition section. The shape of this guide resembles an "S" and is called the S-track (Figure 8).

As defined before, the mid-bay elbow joint controls the opening and closing of the bay and therefore a slider block was added to the joint to slide along the S-track.

When the boom is being retracted, the elbow-joint slider engages the S-track causing the longeron to fold and the bay to close. The bottom of the S-track follows the motion of the extension and the bays are sequentially closed and stored in the storage shell area of the canister.

When the boom is being deployed, the force from the fiberglass bow onto the elbow joint is reacted by the S-track. The top of the S-track is curved to gently ease the elbow joint into place. After a bay is opened, its base is engaged by the elevating nut which lifts it out of the canister. Since the bottom of one bay is the top of the next one, as a bay is lifted out of the canister, the following bay is going through transition. In this way the bays are sequentially opened in a continuous motion.

The S-track design is an excellent deployment/retraction device because it:

- uses no moving parts
- works continuously in either direction
- is reversible at any time
- uses the motion of the boom for power
- occupies minimal area
- is automatically synchronized with the boom.

#### VARIATIONS AND OTHER APPLICATIONS

The elevating mechanism for this system is the large rotating nut but another method can also be used. Variations of this boom have been designed and built which are self deploying and lanyard controlled. This method of deployment results in a much lighter and smaller system but full strength and stiffness are not obtained until the boom is fully deployed. A larger version of this boom based on a 2.7 M (108 inch) cube has been built and tested for large-scale applications such as the space station. Although this type of boom is difficult to build smaller than a 16" cube, the upper limit to size is limited by the size of the launch vehicle.

## CONCLUSION

The boom and deployment mechanism for the tethered satellite program have been designed, built, and qualification tested. The tests included operation at high and low temperature as well as loading to determine strength and stiffness. Results of this testing show that the mast meets all of the imposed requirements.

This boom was developed to satisfy the need for a larger and stronger deployable structure that can stow in minimal volume. The design goals were achieved by using this unique and recently patented folding boom. Fabrication and acceptance testing are currently in progress for a flight system scheduled to launch in 1988.

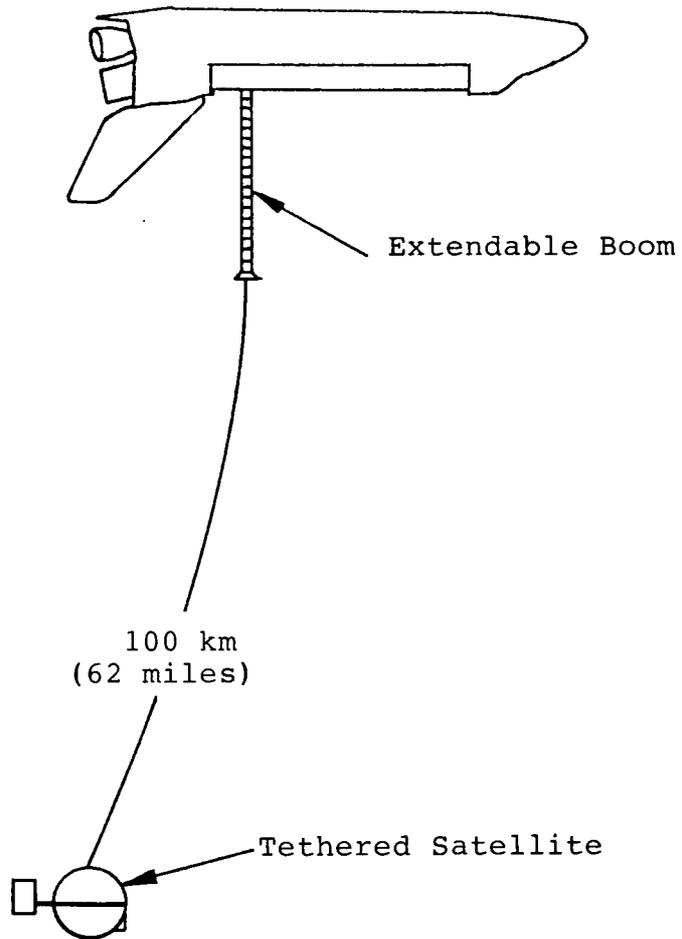


Figure 1: Tethered Satellite Experiment

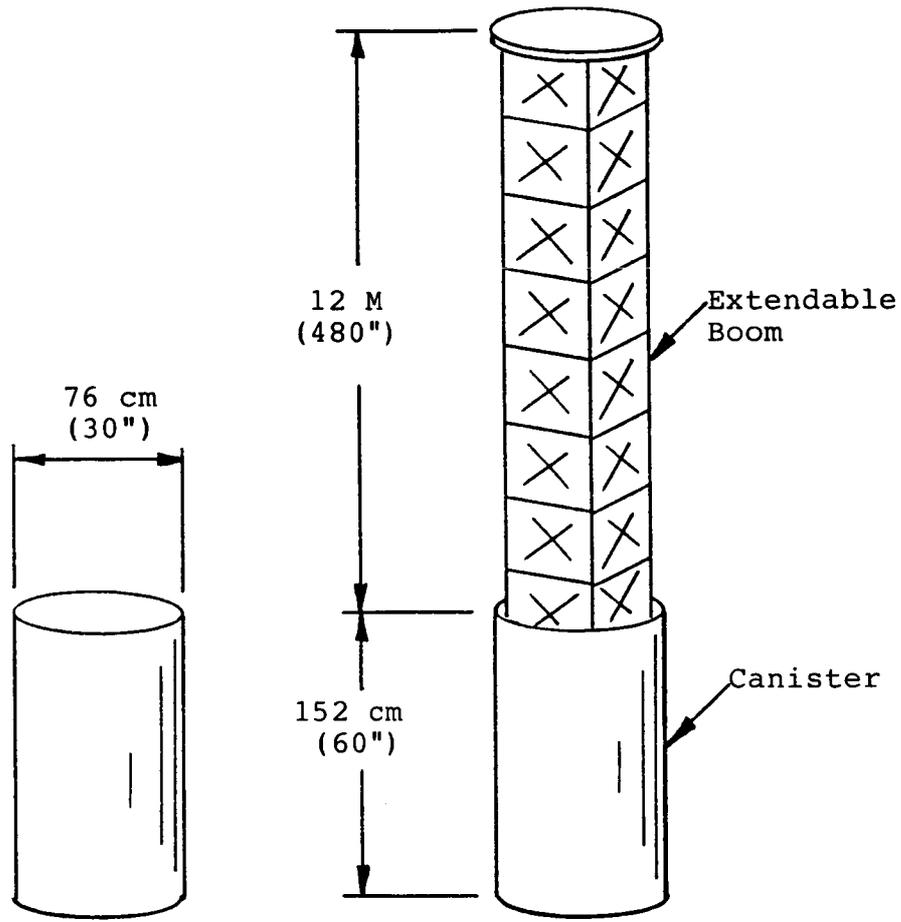


Figure 2: Envelope Dimensions

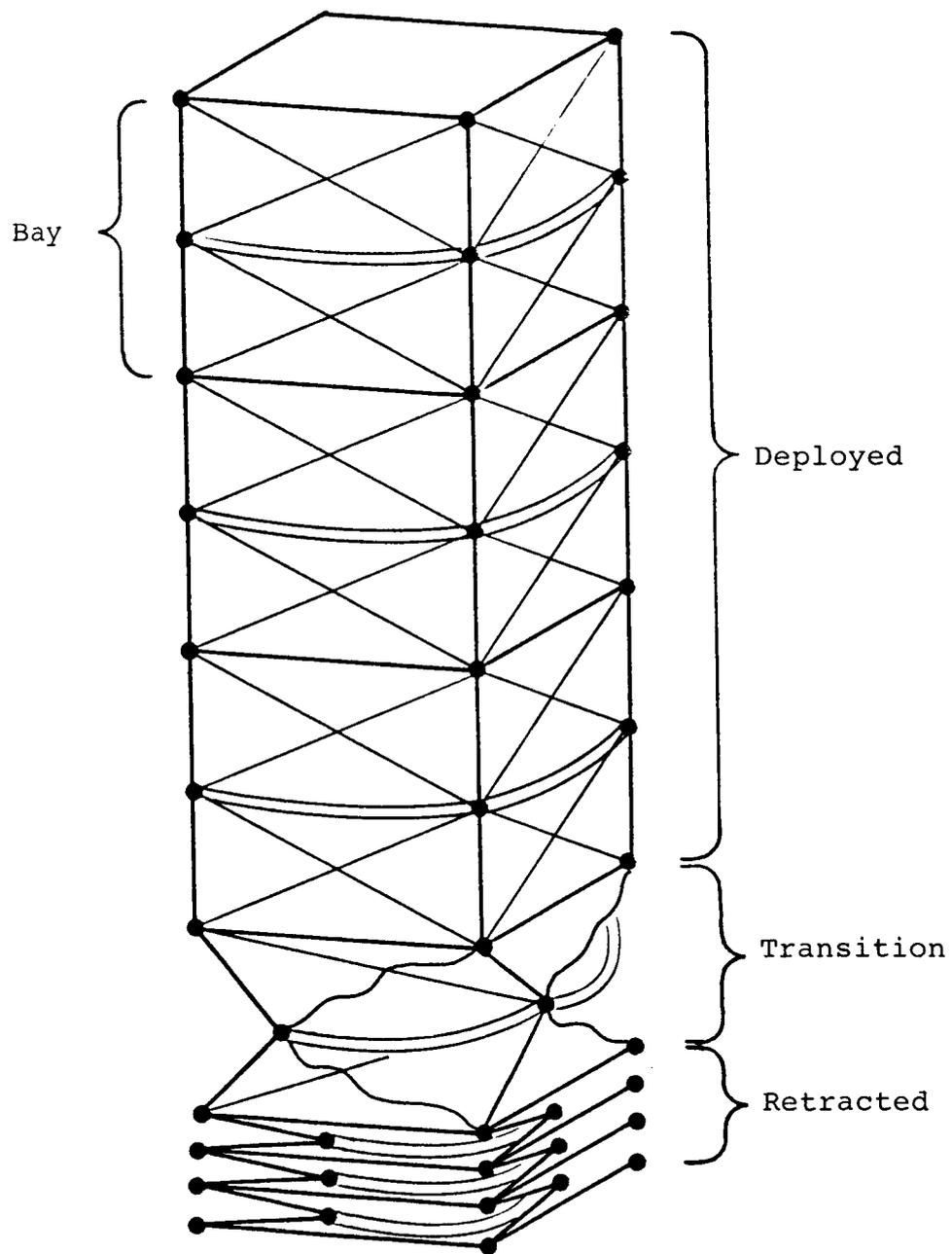
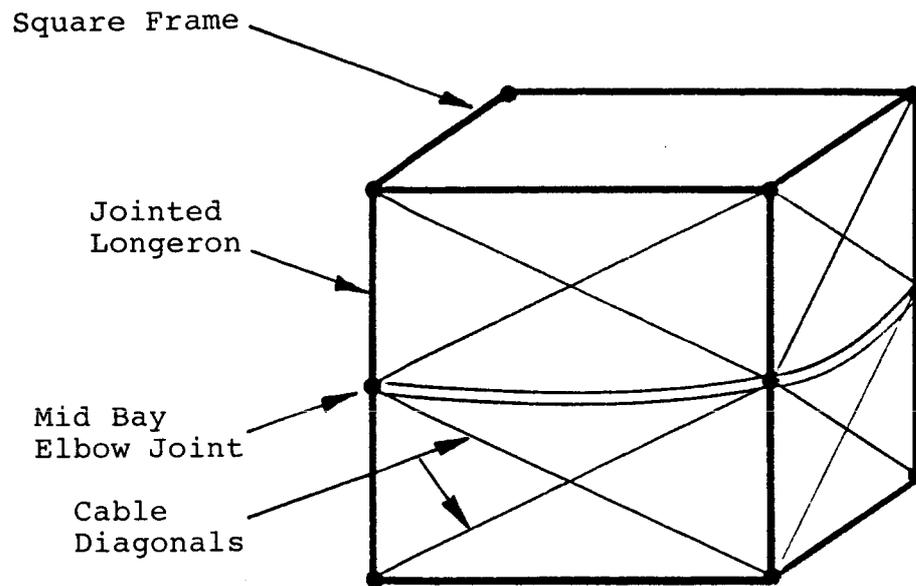
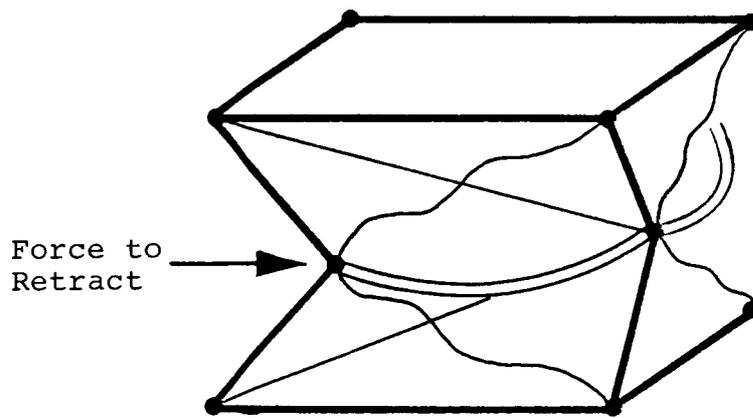


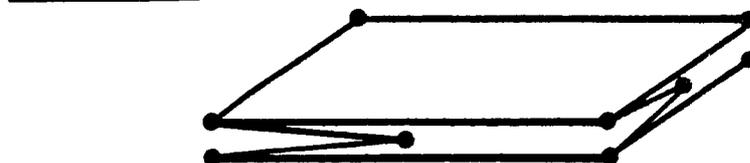
Figure 3: Boom Description



OPEN BAY

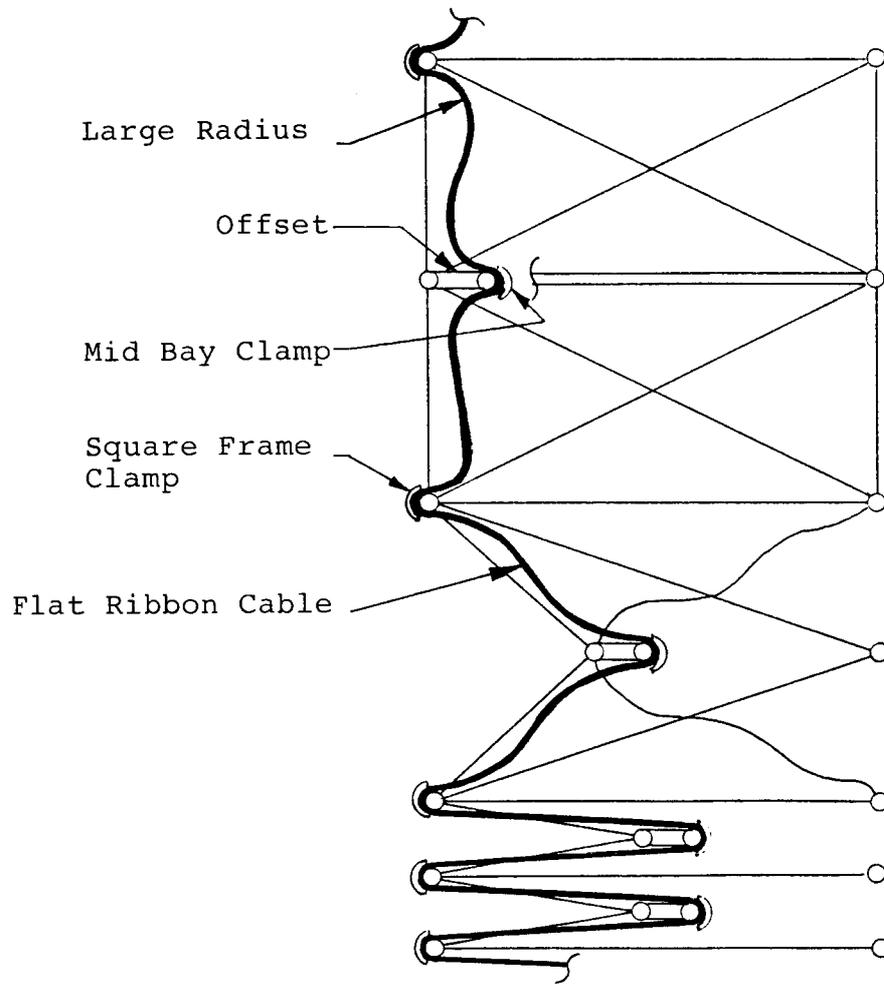


TRANSITION



CLOSED BAY

Figure 4: Bay Components



One Face Only Shown

Figure 5: Electrical Cable

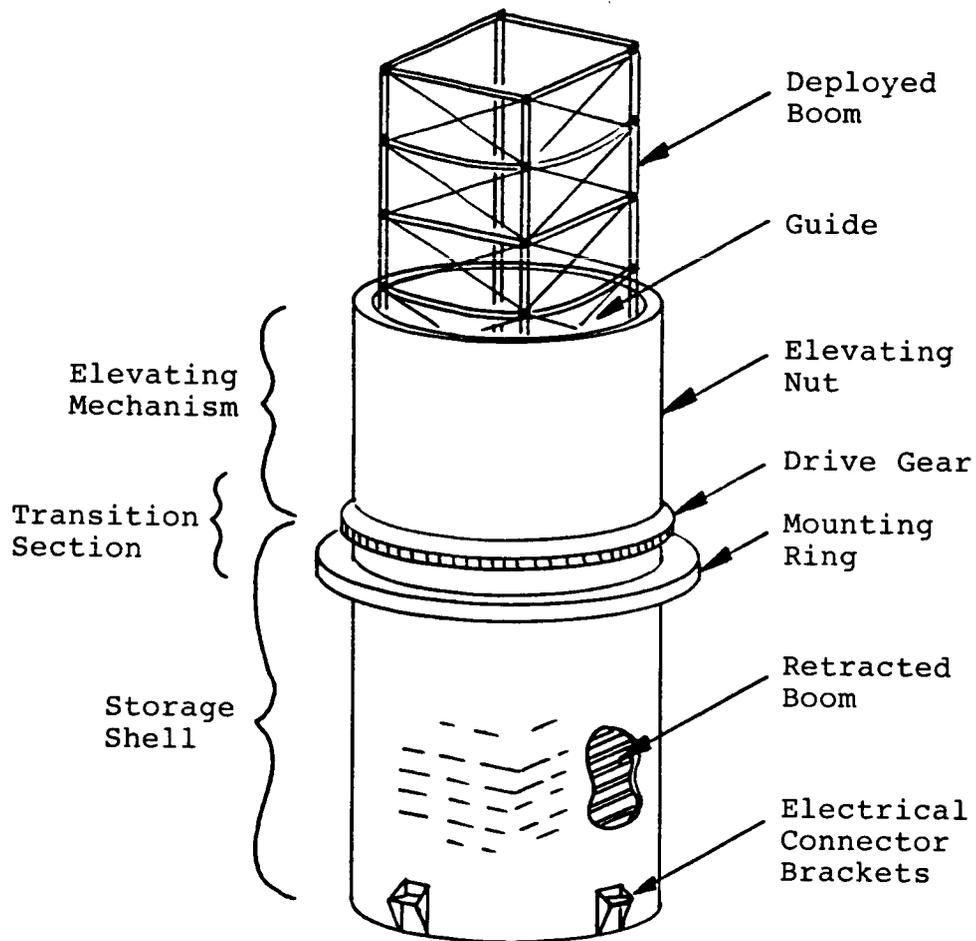


Figure 6: Canister Description

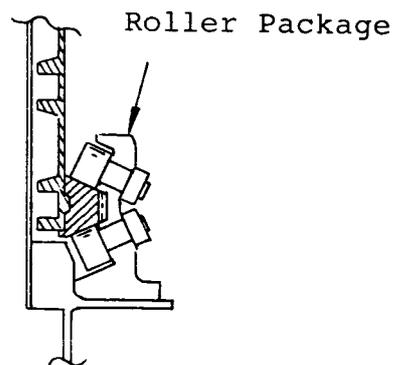
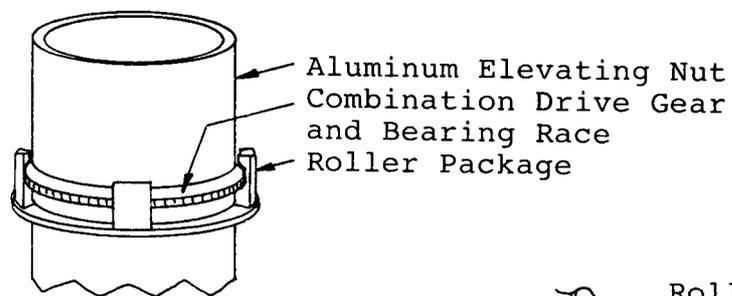
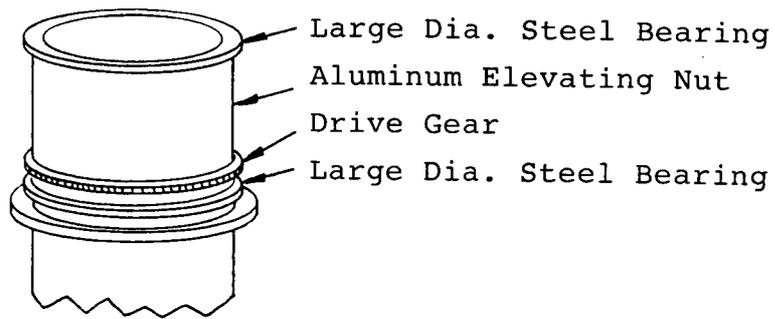


Figure 7: Bearing Comparison

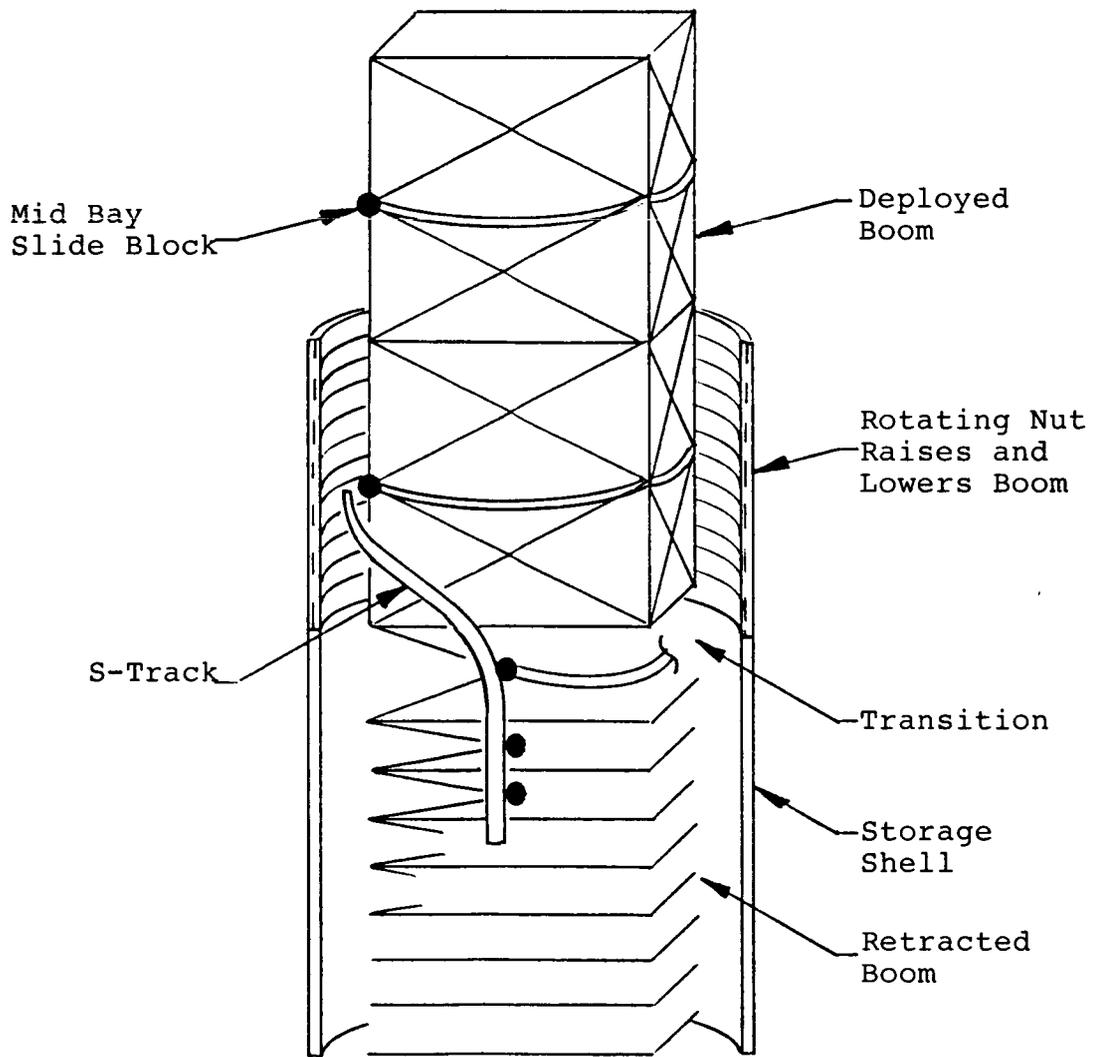


Figure 8: S-Track Function

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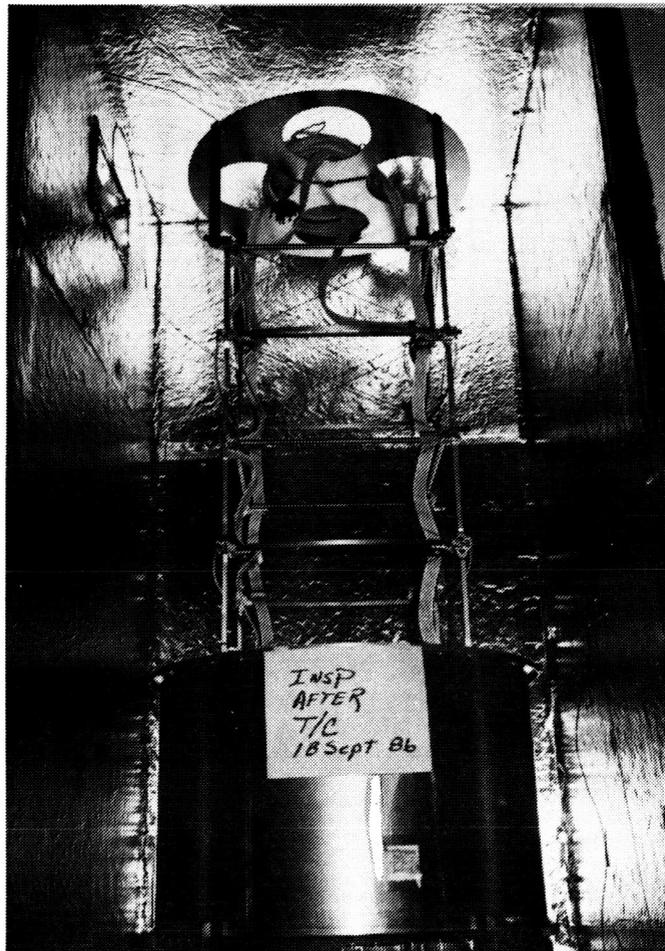


Figure 9: Boom Deployed in Thermal Chamber

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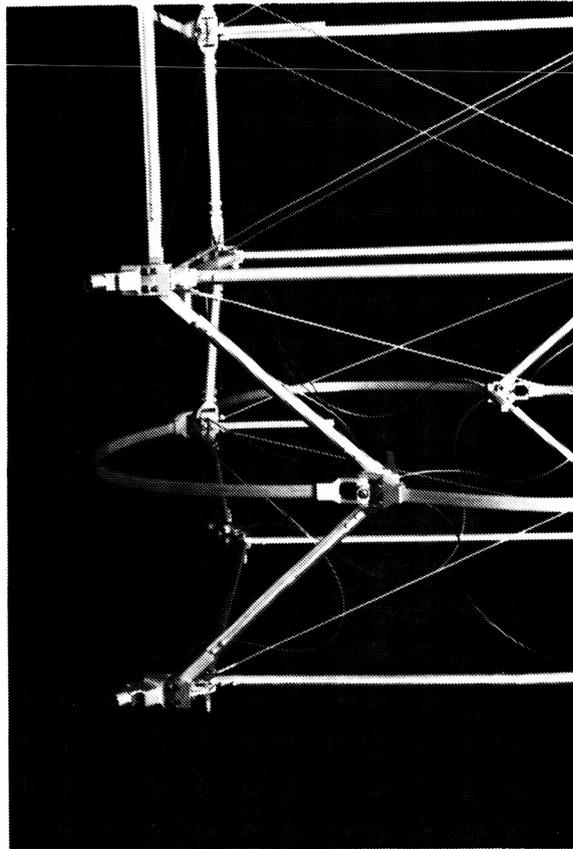


Figure 10: Bay in Transition